Mine Water Inrushes Foreseeable with Specific Humidity Control of the Vetilation Air

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ABSTRACT

The paper illustrates a method that makes it possible to foresee the risk of water inflows on the basis of systematic monitoring of the specific humidity variation of the air as it crosses mine workings subject to flooding or water inrushes. After a description of the first experimental results, the limitations of the method are discussed and the parameters to be considered for correct interpretation of the thermohygrometric data are indicated.

INTRODUCTION

When flooding or water inrushes occur the most conspicuous events preceding them should be identified since their reoccurrence could give warning of new floods similar to the ones observed.

In a mine in southern Tuscany, for example. during the digging of a long gallery in clayey-sandy formations subject to continuous gas inflows and spontaneous inrushes of water and mud, it was found that the inrushes were preceded by: sudden increases in the hydrostatic pressure behind the face, presumably due to the reconnection of superposed water tables; increases in the gas flow rate; and gradual increases in the flow rate of the seepage water that systematically came from the face.

In similar cases it is clear that the water inrushes can be foreseen by identifying these variations, particulary the increase in the seepage water at the face. This increase can be detected from the higher specific humidity of the air ventilating the face, which is the principle the forecast method proposed here is based on.

CONTROL OF SEEPAGE WATER BY MEANS OF THERMOHYGROMETRIC MONITORING

The variation of one parameter of a vetilation current going through a gallery and in general any part of a mine, changes (transient regime) or stays the same (stationary regime) according to whether or not the factors influencing that parameter change. Thus, if the amount of water present in the gallery increases or decreases, in the case of evaporation the variation of the specific humidity of the ventilation air would either increase or decrease.

When saturation conditions are not reached, it is possible to check the differences in specific humidity of the ventilation air between the ends of a gallery to detect whether water infiltrations arise, increase or decrease in it. Hence, all floods and water inrushes preceded by infiltrations can be foreseen by continuous monitoring of these differences.

It is clear that in order to unequivocally attribute an increase in the variation of specific humidity of the air crossing a suspect gallery to an increase in water inflow, the effects of the various parameters influencing the change of state of the water impinged on by the air must be taken into account. Evaporation and condensation of water in an airway depend on:

- the thermohygrometric conditions of the air at the mouth of the airway
- the velocity of the air
- any water present in the airway
- the water temperature and the way the water presents itself (stagnant water, humid walls) and/or enters (seepage, concentrated inflows) into the airway
- the rock-air heat exchange
- the temperature variation of the air due to expansion or compression if the airway is a shaft or an slope.

Since these parameters mutually influence one another it would be necessary to solve very complex multiple correlation problems. But solutions giving sufficiently exact general evaluations of the overall effects could never be reached, seeing that the cited parameters present themselves, vary and influence each other in different ways from case to case. Therefore, for each gallery the influence of the various factors must be experimentally investigated in order to correctly identify the increases in the specific humidity variations attributable to new inflows or to increases in preexisting inflows.

WATER INRUSHES AND INFILTRATION

In a gallery dug in permeable formations (prevalently silty and sandy formations, for example) subject to hydrostatic loads, water infiltrations occur which, if the loads increase, become more and more intense before degenerating into inrushes of water and mud. The collapse of a pillar will occur only when its resistance, which gradually declines due to the interstitial pressure(1) and the continuous removal of material, becomes insufficient to withstand the hydrostatic pressure reached in the meantime. The increase in the flow rate of infiltration water, which precedes the possible inrush, is governed by the increase in hydrostatic pressure and the amount of material removed.

In a gallery dug in karstic rocks, locally resistant, impermeable and unaffected by the mining, the water would penetrate suddenly if fractures in communication with water bodies were encountered(2).

In this second case, unlike the first, there are no water infiltrations before the inrushes and therefore such inrushes cannot be foreseen by monitoring the specific humidity of the air that has ventilated the gallery.

Table 1.

Situation	Measurement point	t_d (°C)	φ (%)	x (mN/N)	$x_B - x_A$ $x_C - x_B$ (mN/N)	h (kJ/N)	v (m/s)
	A	32.7	43.2	13,77		6,96	
1	B	31,5	44,2	13,13	-0,64	6,67	2,23
	C	30,5	48,8	13,69	0,56	6,71	2,55
	A	32,5	46,0	14,50		7.13	
2	B	31,9	47,1	14,29	-0,21	7,01	2,23
	C	30,5	51.8	14.57	0,28	6,94	2,45
	A	31,8	41,0	12,38		6.49	
3	B	31.4	41.5	12,28	-0,10	6.43	2,23
	C	30.4	45.9	12,86	0,58	6,48	2,45
	A	32.8	45,6	14,62		7.19	
4	B	32.0	47,3	14,46	-0,16	7,07	2,27
	C	30.7	51.7	14,69	0,23	6,99	2,55

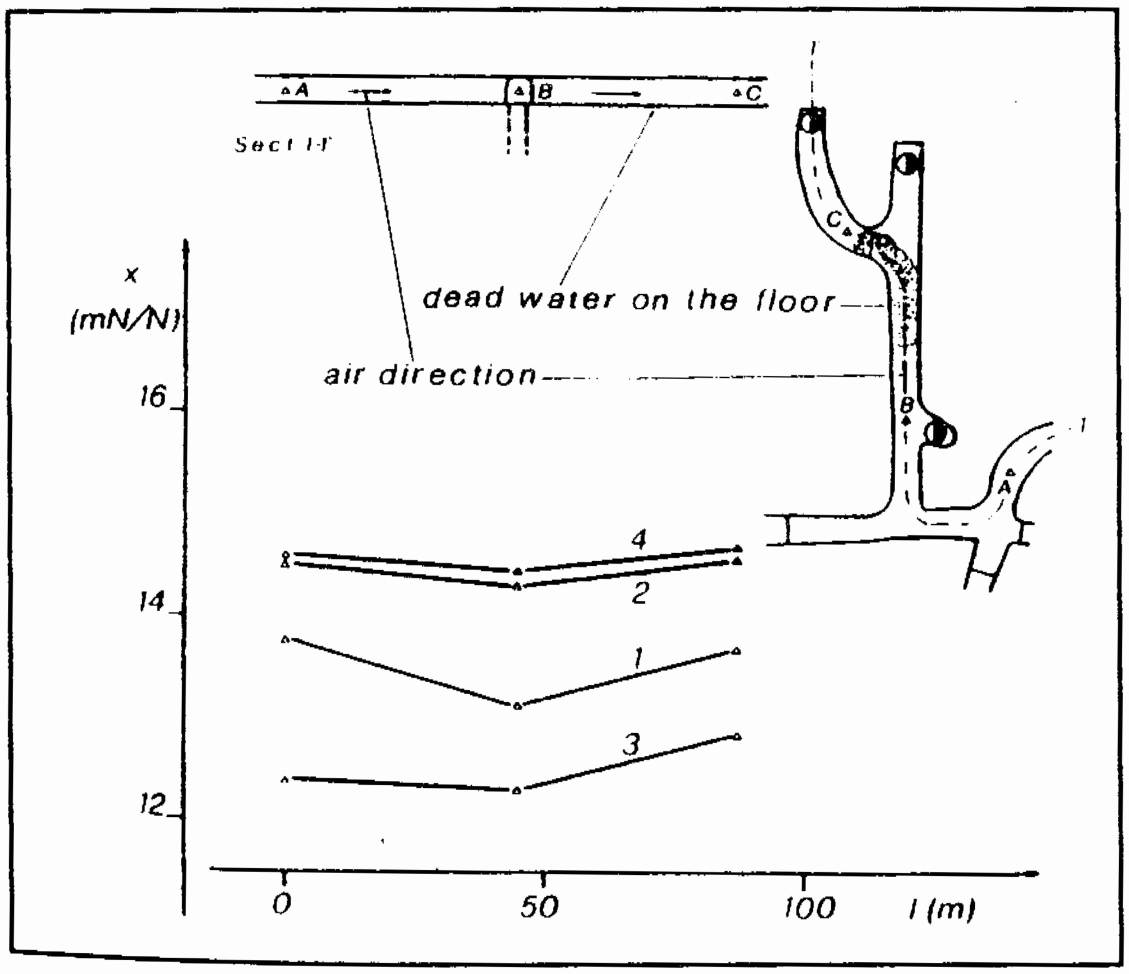

Figure 1: Specific humidity of a ventilation air of a gallery, which is dry in section AB and has water on the floor in section BC

Table 2.

Measurement point	t_d (°C)	t_w (°C)	φ (%)	x (mN/N)	h (kJ/N)
A	34.2	19.5	21,1	7,33	5.44
B	34.6	20,6	20.3	7,21	5.45
C	36.1	20,2	19.4	7.45	5,66
D	36,7	20.2	18,7	7.41	5,72
E	37.7	20,3	17.7	7.37	5.81
F	38.4	20.5	17.2	7.45	5.90
G	38.5	20.6	16,8	7,82	6.01
H	39.5	21.2	16.8	7.67	6.08
I	39.4	21.0	17,0	7.71	6.08
L	39.1	21.3	17.8	7,90	6.10
M	38.6	22.3	20,2	8,84	6,29
N	37.7	22.9	26.6	11,19	6.81
O	37.3	25.2	36.2	14.86	7.73

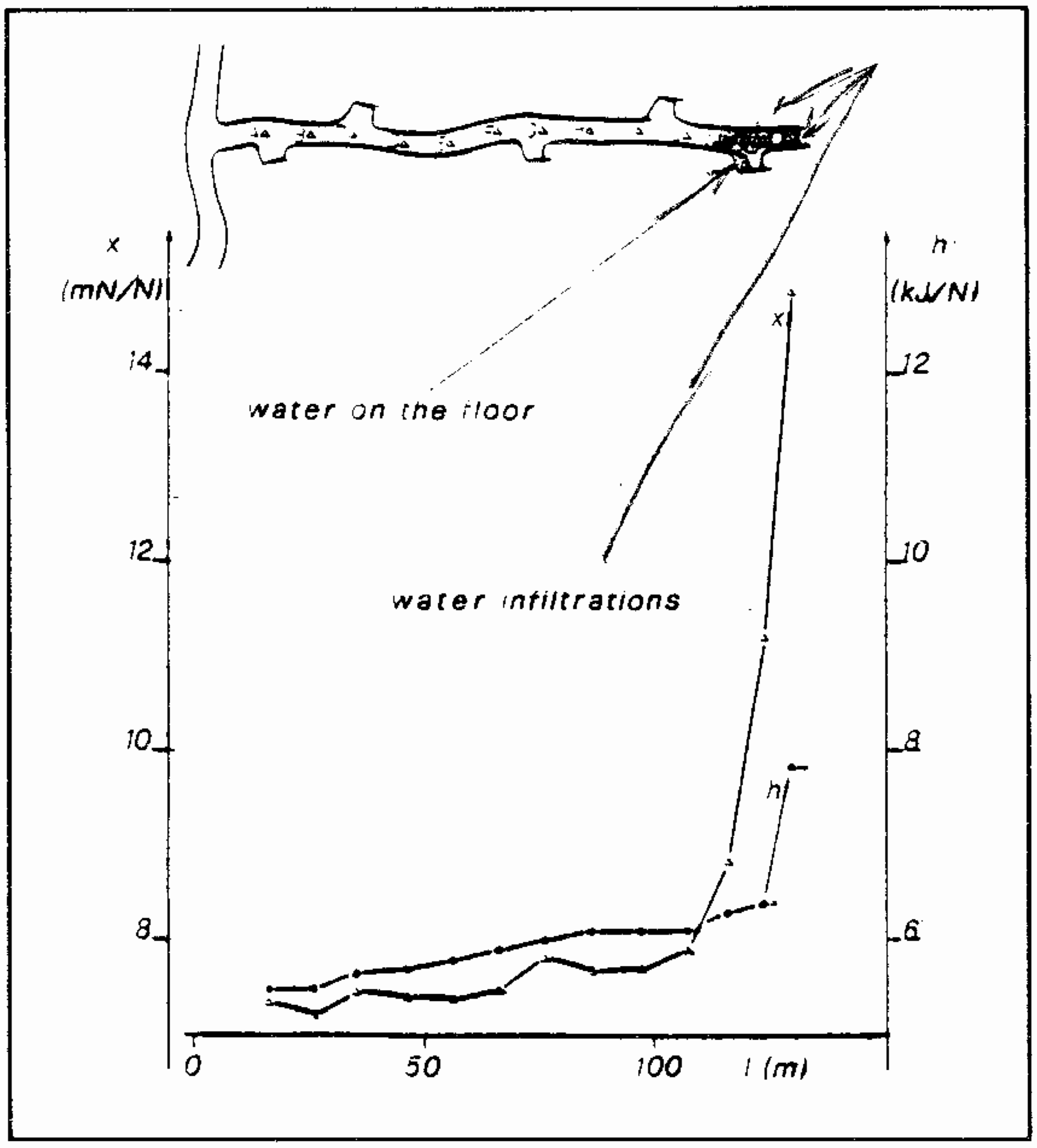

Figure 2: Specific humidity and enthalpy of the air in a dead end gallery without mechanical ventilation and with water infiltrations on the end walls and face.

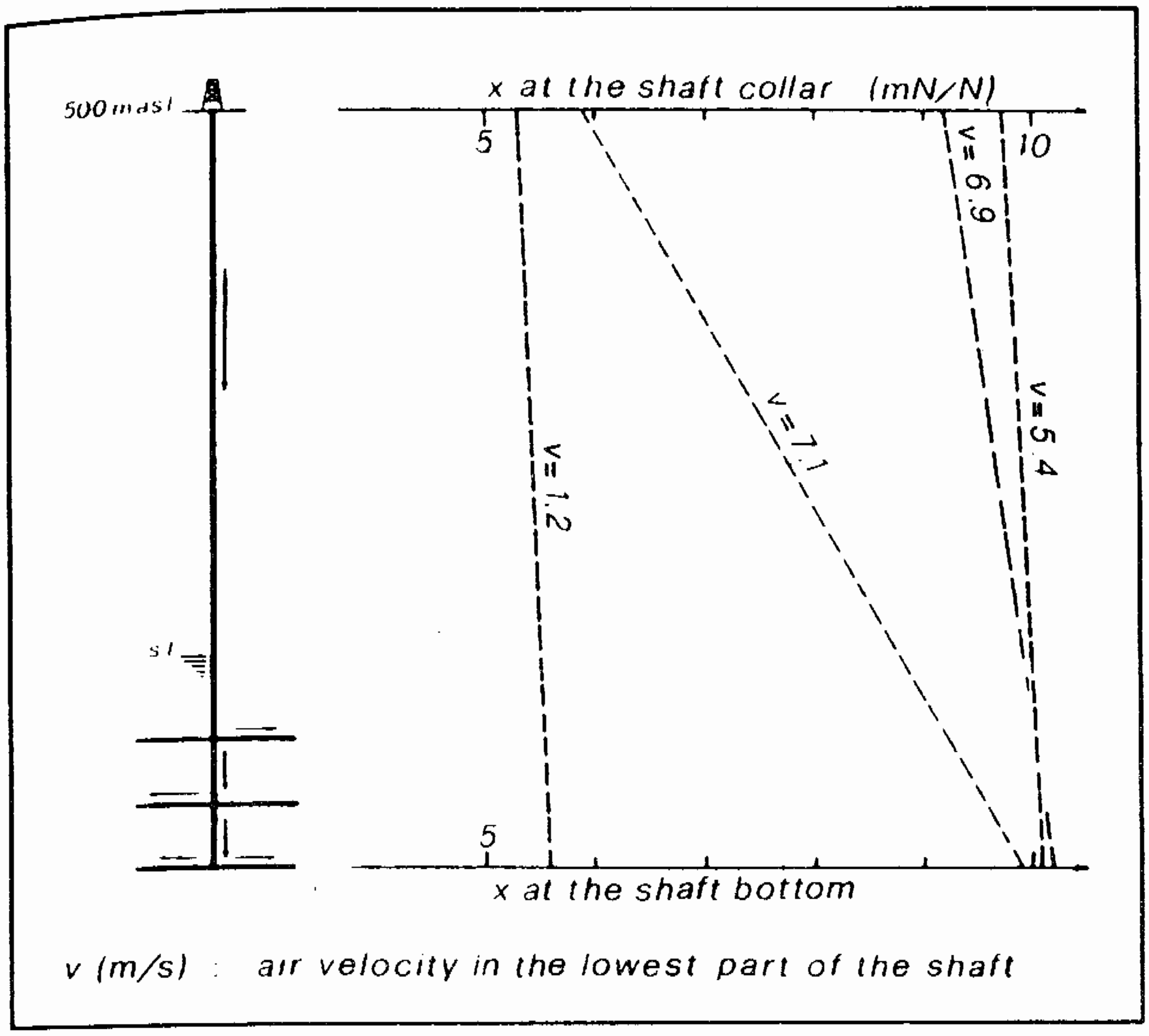

Figure 3: Dependence of evaporation in an air intake shaft on the specific humidity at the collar and the velocity.

The cases described are extreme cases between which intermediate ones can be placed, as follows: water inflows due to the increase in the hydraulic conductivities of the strata overlying longwall workings(3) ; wet rock material inrushes(4) ; accidental connections of present workings to old flooded mine workings(5) ; water inflows from the initially unsaturated rocks(6). For these cases the control method described here can be applied just the same, but it absolutely cannot be considered a sufficient means of prediction because during their evolution the water does not always manage to seep into the mine workings before rushing in.

RESULTS

To check its efficacy in the various situations, the method in question has been experimented with in mine galleries and shafts in southern Tuscany by determining, in preestablished points, the following ventilation air parameters: dry temperature, t_d; wet temperature, t_w; relative humidity, ; specific humidity, x; enthalpy with reference to dry air at 0°C, h; and velocity, v. The results obtained so far are summarized below.

Table 1 shows the data relating to the gallery drawn in Figure 1, which is dry in section AB and has stagnant water in section BC. The same figure shows the trend of the specific humidity of the air along this gallery, assuming the variations between two successive stations to be linear, in four different circumstances. The presence of the stagnant water is indicated both in the table and the figure by the increase in the specific humidity of the air (evaporation) as it passes from B to C, preceded by the decrease (condensation) corresponding to the passage of the same air in the dry section AB.

Table 2 reports the data regarding the dead end gallery drawn at the top of Figure 2. At the end of this gallery, dug in rock at high temperature, without mechanical ventilation, in correspondence with stations M, N and O are puddles of water up to 0.2 m deep and water infiltrations at 62°C and with an overall flow rate of $2x10^{-4}$ m^3/s. In this case the high temperature of the water and the high gradients according to the axis of the gallery of the heat flow from the rock to the air at the end, which are shown by the trend of h, increase the evaporation and cause the high increments in specific humidity corresponding to the seepage zone that are seen in Figure 2.

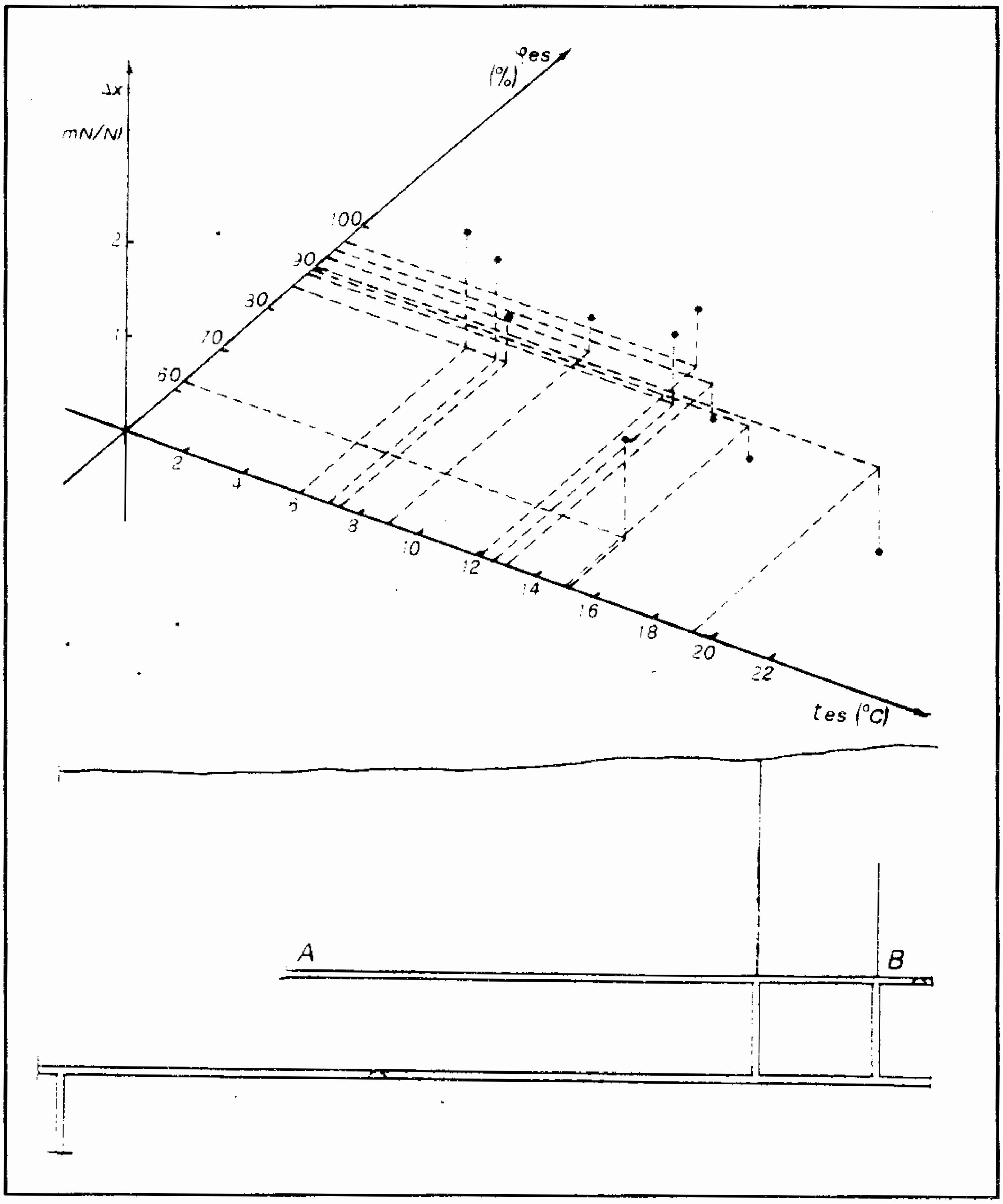

Figure 4: Variation of specific humidity of the ventilation air in crossing, at a speed of about 4 m/s, the gallery section AB with the mouth on the outside as a function of the dry air temperature and the relative humidity at the mouth.

As for the influence of some parameters on evaporation, Figure 3 shows how the increase in the specific humidity of the air during passage in a 700 m deep shaft grows with decreasing specific air humidity at the collar of the shaft and increasing air velocity inside the shaft. As a result, to take determining factors into account a three-dimensional representation (increase in the specific humidity of the air during its passage in the airway as a function of the dry temperature and the humidity at the mouth of the airway) would be needed for each suspect airway to show parametric surfaces in the air velocity so as to establish, for each possible velocity value, a boundary between the zone relative to reductions of water inflows in the airway, situated below the surface, and the zone relative to increases situated above it. At the top of Figure 4, data obtained experimentally delineate one of these surfaces for a section of gallery with the mouth on the outside, drawn at the bottom of the same figure.

The inapplicability of the method in question in the case of rocks that are permeable due to fractures (allowing percolation) has been experimented with by determining the thermohygrometric parameters at the mouth and exit of galleries dug in rocks of this type before and after significant increases in the hydrostatic pressure around them deliberately caused by closing drainage holes.

CONCLUSION

By integrating the proposed method with others it is possible to decisively improve the reliability of forecasts of potential water inflows that can be identified with the method and to foresee other which do not lend themselves to it(7.8.9). Using up-to-date monitoring techniques it is possible to extend the forecasts simultaneously to all the suspect underground zones.

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